Fast Forward for Food's Future

Prof. dr *ir*. Karin Schroën

Inaugural lecture upon taking up the post of Personal Professor of Food Microtechnology at Wageningen University on 4 July 2013

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How understanding effects at micrometre scale will help revolutionise food

Rector Magnificus, colleagues, family and friends

In this inaugural speech, I would like to take you to the field of food microtechnology where length scales are counted in micrometres, or one thousandths of a millimetre. This is the typical length scale of structures in foods that determine their behaviour also when produced at large scale. Besides, these structures are mostly formed at very short time scales, and that is an additional challenge when trying to investigate their formation.

You may wonder why this would be relevant, since foods and food ingredients are produced at very large scale on a daily basis. Surprisingly enough, insight in the underlying mechanisms that take place at micrometre scale is mostly lacking, and that is why I want to explore this field, learn from it, and incorporate this into food process technology; or go into fast forward mode to establish the food products of the future, and the processes needed to make them. To illustrate this, I will show examples from current research on emulsification and ingredient fractionation, and illustrate in which direction this research is expected to develop. Although primary targeted at food, I would like to point out that the knowledge that is generated can be applied much more widely than 'just' for food, and also some other examples are included in this lecture.

A little piece of history

Before telling you about food microtechnology, I would like to take you back in time for a short while. When preparing for this lecture, my colleague Anja Janssen drew my attention to the archives of the food process engineering group that we are currently digitising while preparing to move the group to another location in Wageningen. It was very interesting to read the words of professor Leniger about what was then the laboratory of technology of the 'Landbouwhogeschool', and also to see some images of what the actual labs looked like. As you can see here, the labs contained a lot of stainless steel, and I will come back to that later.

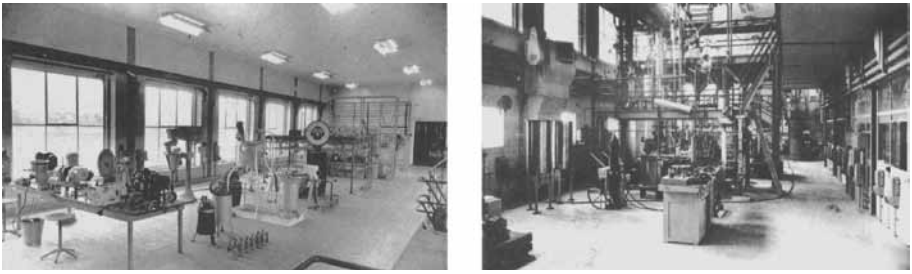

Figure 1. Semi-technical labs in 1955.

What was even more interesting was the view of professor Leniger as written down in 1980, on how science has affected the food industry. The original was in Dutch, and in translation this came down to the following:

'An important feature of the food industry is that it is not science-based. Experience and tradition played the leading roles, and have continued to do so. ….. Knowledge and insight have increased spectacularly in the last half century. Still I dare to say that food science has not played a leading role in the development of the food industry. At most there was some support'.

As mentioned, these words were written down in 1980, but they still contain an essence of truth. Tradition and experience are still there, and are found important in the food industry, and also by the consumers. The position of science and how we collaborate closely with partners from food industry has changed considerably since then; and exchange of information has become much faster. But still if I think about the product innovations that we all can see in the supermarket, I cannot help coming to the conclusion that a lot of innovations are still on the level of relatively small changes in ingredient composition, and a variation on already accepted products. Obviously this also has to do with the competitiveness of the food market. Applying completely new process technology will only take place if this technology is proven

and has shown to be able to handle large product flows. But there is also another aspect that in my view has not been covered sufficiently to allow for rigorous changes in food processing based on scientific investigations, and that has to do with the fact that all mechanisms that are responsible for the formation of the structure of many foods take place at micrometre scale and mostly at very short time scales. Standard tools simply don't allow observations at these scales, and this is where food microtechnology comes in.

This may be a bit abstract, so allow me to take you to an illustrative example, ice cream. Ice cream consists of milk fat, protein, sugar, some minor components and a lot of air, ~50%. In the image that is shown here, the big spherical structures are air bubbles, which are surrounded by small fat crystals that are formed upon cooling of the ice cream mixture, and that give the ice cream its structure. Before cooling, the fat is present as small liquid droplets which allows for equal distribution of the fat over the ice cream mixture. The droplets in turn are stabilised against coalescence by the protein that is present in the ice cream mix. This is a very simplified description of how the ice cream structure is built; but the message is clear, it is all about stabilising interfaces that are formed, be it the air liquid, or fat liquid interface.

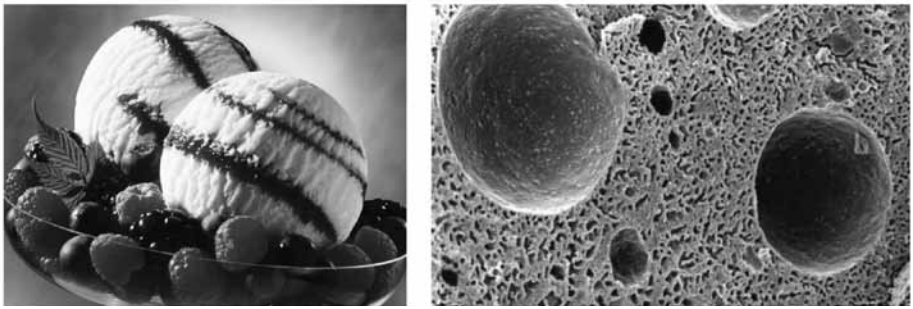

Figure 2. Ice cream, and scanning electron microscopic image of ice cream. The large objects are air bubbles stabilised by small fat crystals, which in turn are surrounded by a protein matrix.

Everyone will have appreciated a nice ice cream on a warm summer's day, but it may surprise you that not that much is known about how the stabilisation of the interfaces that basically determine what ice cream is. The actual composition has been probed, so that is known, but what happens during formation of the ice cream is not known. This is not only true for ice cream but for many food products.

To illustrate how this knowledge base could be strengthened, I would like to discuss two examples, one about emulsification, and one about ingredient fractionation with you, and show how knowledge at micrometre scale is essential to first understand

what is happening, and also to develop new process technology based on these findings.

Emulsification

An emulsion is a mixture of oil and water as was the case in the ice cream mixture prior to aeration. Normally, water and oil don't mix, so energy needs to be supplied as are components that are able to stabilise the formed interfaces, so called emulsifiers. When looking at the energy needed to make the interfaces, it becomes clear that the supplied energy is much more than needed to form the interfaces. Typically more than 95% of the supplied energy is not used effectively, either because it is dissipated as heat, or because the formed interfaces are not stabilised fast enough to prevent coalescence.

Various emulsification techniques can be used, and at the Technical University of Karlsruhe in Germany an illustrative graph was made that compares these technologies. There is a big difference between traditional emulsification techniques such as high pressure homogenisers, and colloid mills that are orders of magnitude higher in energy usage as compared to relatively new techniques such as membrane emulsification. The main difference is that classic emulsification techniques start with a mixture of all emulsion ingredients that are subsequently pushed through a narrow gap, which results in droplet formation. In membrane emulsification, droplets are formed one by one. The to-be-dispersed phase is pushed through a membrane, which is a sieve with very small pores, and the droplets formed on top of the membrane are sheared of by the cross-flowing continuous phase. Depending on the required amount of droplets the energy that is needed changes as is also indicated in the graph, going from 1 to 50% droplets.

For membrane emulsification various scaling relations have been suggested, but there is still a lot of discussion, regarding the droplet formation mechanism, and which parameters including the membrane structure influence the size of the droplets. For cross-flow emulsification, there is no general consent on what is most relevant; it is claimed that both the properties of the continuous phase and the to-be-dispersed phase, the pore size distribution of the membrane, the wettability of the surface, and on top of that the interfacial tension which is a result of component adhesion to the interface all influence the droplet size. This dispute is also fed by the fact that direct observations are extremely difficult, and computer simulations are only sparingly available.

In order to discriminate between all these factors, microfluidic channels are ideal tools, which in combination with fast imaging allow for observation at relevant

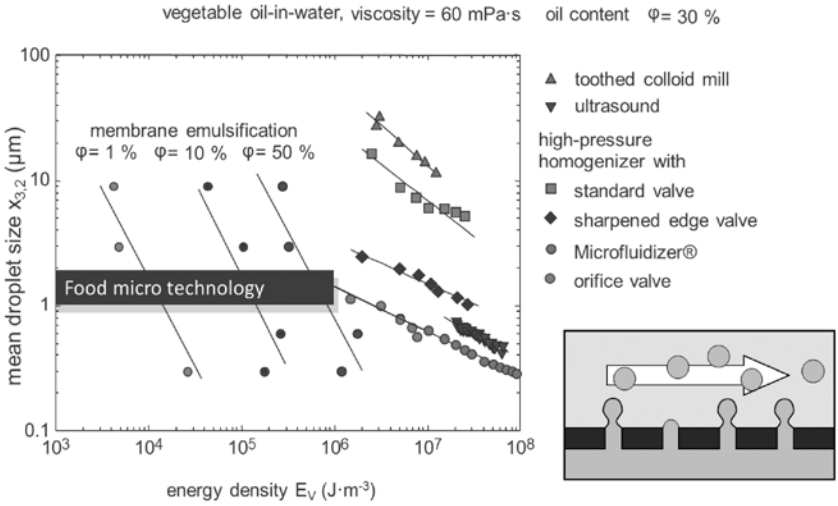

Figure 3. Comparison of various emulsification technologies based on energy density. The graph is adapted from: Schroeder, PhD thesis, TU Karlsruhe. Right bottom insert: principle of cross-flow membrane emulsification; the to-be-dispersed phase is pushed through the membrane and the droplets are sheared of by the cross-flowing continuous phase.

scales, both in regard of time and size. This together with detailed computer simulations has allowed us to investigate various emulsification techniques.

In our lab we developed a new emulsification technology called EDGE, edge-based droplet generation, within the PhD project of Koen van Dijke, and here I would like to show how all these elements came together and led to a new approach to make monodisperse, equally-sized, droplets. The microfluidic chip consists of a supply channel through which oil is pushed onto a wider area, called the plateau. This plateau is very shallow; the one in this movie is only 2 micrometres deep. Upon reaching the end of the plateau the oil can expand into a deeper channel, and locally droplets start forming amongst others due to Laplace pressure differences, as shown in the computer simulations. The combination of microscopic observation and computer simulation has led to scaling relations that comprise all relevant parameters without the need of introducing fit parameters. Interestingly, in EDGE emulsification, the size of the droplets is to a very large extent determined by the height of the plateau, with the droplet size being approximately 6 times that value. It is also worthwhile mentioning that the energy usage of such microfluidic chips is as low as was the case for membranes, so that benefit is maintained, and also the droplets are extremely monodisperse compared to other emulsification techniques, with coefficients of variation of only 5%.

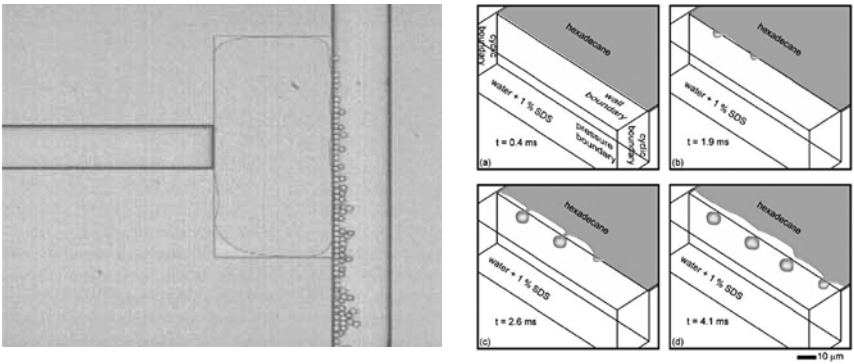

Figure 4. EDGE emulsification as recorded by high speed imaging (left) and by computer simulations (right). The to-be-dispersed phase is pushed onto the shallow wide plateau. Upon reaching the end of the plateau, droplets can expand into a deeper channel where they spontaneously snap off due to (Laplace) pressure differences (van Dijke et al, 2009).

Fractionation

From the emulsification example it is clear that equally-size droplets can be made very efficiently; but there are many raw materials in which components of various sizes are present. In that case separating the particles or droplets from the mixture may be the better option. A nice example is milk, in which fat droplets of various sizes, casein protein micelles, serum proteins, and various smaller components are present. In a microscopic picture milk looks as follows, with cream droplets of different size visible. An accepted technology to separate some milk components is membrane filtration, although not for fat separation, that is known to give many issues. When zooming in on a regular microfiltration membrane with a nominal pore size of 0.2 micrometre, it is clear that a membrane contains pores of many different sizes. When carrying out a separation, all the components in the milk are pushed toward the membrane, where they accumulate, and that is the reason why separation of micrometre sized particles is challenging. Depending on the back transport mechanism of the particles they may move away from the membrane, but it is clear that the process needs to be operated with care since pores are prone for blockage by the particles that are larger than the pores.

Also for membrane filtration we have taken a similar approach as previously described for emulsification. So we used observation on very small scale, in this case glass channels through which were particles flowing. These observations were carried out within the PhD project of Anna van Dinther by Confocal Scanning Laser Microscopy that allows tracking of the position of fluorescent particles of different sizes. Although it is known that particles can exhibit different migration behaviour depending on their size, it was surprising to see the big differences in behaviour of

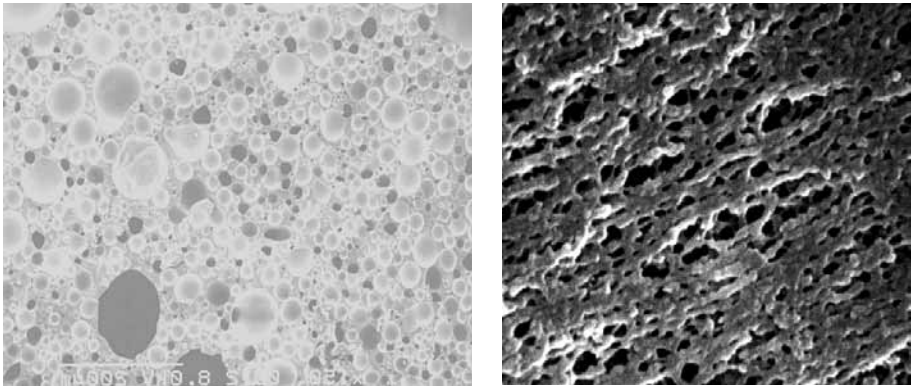

Figure 5. Light microscopic images of milk (left), and a scanning electron microscopic image of a microfiltration membrane with nominal pore size of 0.2 micrometre (right).

particles that all act via the same mechanism and are only a few micrometre in size different.

The particles that we investigated were between 1 and 10 micrometre, and move according to the shear-induced diffusion mechanism, which was also what occurred. In this case, the larger particles predominantly moved to the centre of the channel, while the small particles moved toward the outer regions of the channel.

This was also confirmed in membrane filtration experiments carried out with membranes with large uniform pores, which were preceded by a closed channel that is needed to allow particles to move sufficiently away from the membrane surface. In order to be able to compare all experiments, we used a dimensionless time theta, which is the ratio of the time needed for a particle to sink into the pore and the time needed to cross the pore. At low theta where the particles have a relatively high cross-flow velocity, all large particles pass the pore and are retained by the membrane. Their transmission is zero, while the small particles are exclusively transmitted, even at higher concentrations as present in the feed solution. At higher theta, corresponding to higher transmembrane pressure, more particles are carried toward the membrane and the concentration of small particles in the permeate remains high, while at some stage also large particles start appearing as permeate. Upon further increase of the pressure, the separation is lost and both particles appear in equal amounts in the permeate.

This may not seem that spectacular, but do keep in mind that the membranes that we used had very large pores, that were typically 5 times larger than the largest particle. So there was no physical barrier to keep the particles from permeating the

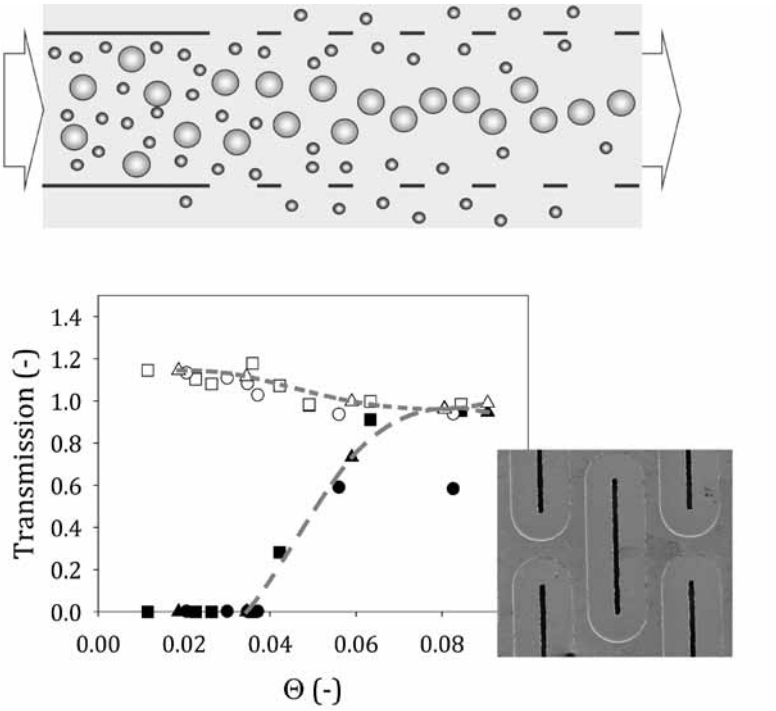

Figure 6. Top. Schematic representation of particle migration in closed channels, with the larger particle moving to the central part and the small ones expelled to the outer regions (Kromkamp et al, 2006). Bottom: Transmission of small (open symbols) and large particles (closed symbols) as function of the dimensionless time (Θ), corresponding to the ratio of transmembrane velocity, and the cross-membrane velocity. The insert shows one of the Stork Veco membranes with uniform pores that were used in the filtrations experiments (van Dinther et al, 2013).

membrane. In regular membranes the size of the pore is smaller than the particle that it is retaining, which results in accumulation of particles, while in the experiments shown in the graph, the particles do not accumulate. Whether they end up as permeate or not is only determined by the cross-flow velocity and the transmembrane pressure, which allows for deposition free filtration under conditions that are remote from what is standardly used in membrane filtration. Still the amount of product that can be made per square meter of membrane is at least as high as found for regular microfiltration (200 l/m²/h).

Depending on the volume fraction of particles in the feed various things were observed. At low concentration, the particles skim over the pore, while at higher concentrations the interaction of the particles takes care of extra back transport, so

away from the membrane, and also in that case, fractionation can be carried out successfully even at concentrations close to the jamming point. The energy required for these separations, can be much lower as in regular membrane filtration, since the cross-flow velocities are lower and far away from the turbulent conditions that are normally used.

From these two examples from emulsification and fractionation it is clear that if effects are investigated at the determining scales, this leads to new insights that in turn lead to options for the design of radically new large scale process technology and new food products, that may be very far from current practice, but are valid genuine options that are worthy of further exploration. Up-scaling of micrometre sized structures is far from trivial, but we have ideas to do so, as I will present at the end of my lecture.

Food microtechnology applications

Encapsulates

What I would also like to discuss with you next is which other options have become available now that we are able to make droplets of controlled size, and know about their behaviour in flow. Both aspects are important when using microfluidic tools to analyse for example stability of emulsions, or make capsules, particles or other related products. These topics are all part of the investigations carried out within the food microtechnology group, and I will share some illustrative examples with you.

Starting from emulsion droplets it is relatively easy to move toward encapsulates. The idea behind encapsulation is that a vulnerable component is incorporated in the droplet, and that the droplet is sealed by a layer that is not permeable. So the component is locked in by this layer, but in order to release the component at the desired time and place, the layer should degrade. This can be done through a change in acidity, addition of salt, enzyme action, basically any trigger that is available. But even more importantly, the capsule should be resistant against all the other conditions it goes through before arriving at the desired location. You can see this as travelling, and needing the right document to move across a border. If you don't have the visa, your trip will not last very long, and you will get stuck in an undesired place.

When thinking about our body, and a component that would need to be released in your intestine as was the case for the project carried out by Francisco Rossier in close collaboration with the food physics group, this means that the capsule needs to be resistant to the enzymes in your saliva, but also to the very acidic conditions in your stomach, while it should degrade later in order to release the component at the right

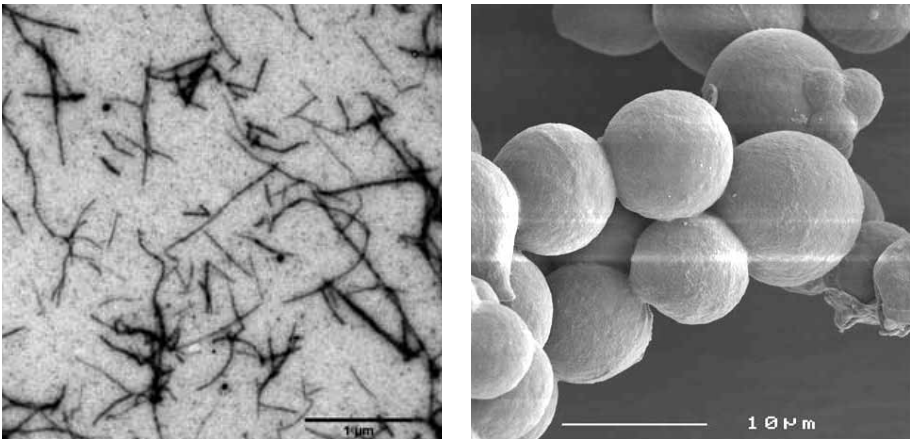

Figure 7. Whey protein fibres produced at low pH (left image) and capsules made by layer-by-layer adsorption of highly methylated pectin and whey protein fibres; total amount of layers is 10 (right image) (Rossier Miranda et al, 2010).

place. Especially resistance against acidic conditions and the mechanical strength of the capsules are issues that are not that easy to comply with.

In literature, various capsules are presented, but mechanical strength is something that is missing in most cases, and that is why it is important to test the various building blocks that may be used in the construction of capsules. We used layer-by-layer adsorption of components with opposite charge, and as extra structural element we used protein fibrils. These fibrils act as fortifying components, comparable to the iron rods used in fortified concrete, and that cover a larger distance and in that way make the capsules mechanically very stable. The first time we tested the capsules in the atomic force microscope, we were happy to have values for their strength. Later we often found the same value, and it turned out that we had been measuring the strength of the machine and not of the capsules. That was easily solved by buying the strongest AFM needle available, but what it comes down to is that these capsules of micrometre-size can be extremely strong.

The next step was to check whether they also would degrade under the right conditions, and that was also the case. The capsules turned out to be very stable under acidic conditions as present in your stomach, but degraded at higher pH as present in your intestine, and this was a very early proof of principle that capsule properties can be tuned accurately. Variation of the components that were used to make the capsules and the conditions under which they were assembled will allow for production of capsules that can be triggered for release in different parts of the

body. Also the components that can be released can be chosen practically at will. Oil soluble components can be directly incorporated in the droplets, while water soluble components could be incorporated into so-called double emulsions, in which the oil droplets contain in turn even smaller water droplets. These double emulsions are not easy to make, but in principle they can be used and capsule formation is not going to be different from what was demonstrated for single emulsions. Whether these capsules are going to be added to food as functional elements, or used as medication, that is still too early to say. But what is sure is that the micrometre sized fibres have played an essential role in preparing mechanically stable capsules, and also in this case the scale at which observations were made was essential.

Particles

In the ice cream example, you have already seen that what are initially droplets can be converted into solid particles, in this case by cooling down the ice cream mixture. This is not the only way to solidify particles; this can also be done by phase inversion, which implies that when starting for example with liquid polymer droplets, they may solidify upon removal of the liquid in which the polymer is dissolved. If this occurs, either solid, porous, or even more complex particles are formed. These particles can be made from various food components as well, including polysaccharides, proteins, and may be used as structural elements in food, allowing for replacement of fat or other high caloric components.

Besides in food, particles can also be used in different fields, such as pharmaceuticals, analytical sciences, and many more. A nice example is the production of ultra sound contrast agents, as we explore within the project of Hassan Sawalha. An ultra sound contrast agent is a hollow sphere with very thin walls as shown here. When subjected to ultrasound it starts vibrating and expanding, which scatters the incoming waves, and allows for visualisation of e.g. blood flow in soft tissues. Here you see the contrast agents flare up at increasing acoustic pressure.

The signal that is generated by the ultrasound contrast agent is amongst others a function of the size of the bubble and the thickness and composition of the wall. Since we are able to make droplets of very accurate size, it was thought that doing this with polymers would also be possible, and it was. It was even possible to incorporate medication inside the ultrasound contrast agent, and release its contents upon increasing the ultrasound pressure, which basically bursts the bubble and allows for very local release of medication, which in turn leads to less overdosing of medication and reduction of side-effects. The potential of these bubbles is great, but it should be mentioned that the interactions between polymer and the membrane that was used to prepare them needed to be controlled accurately in order to be successful. Also the

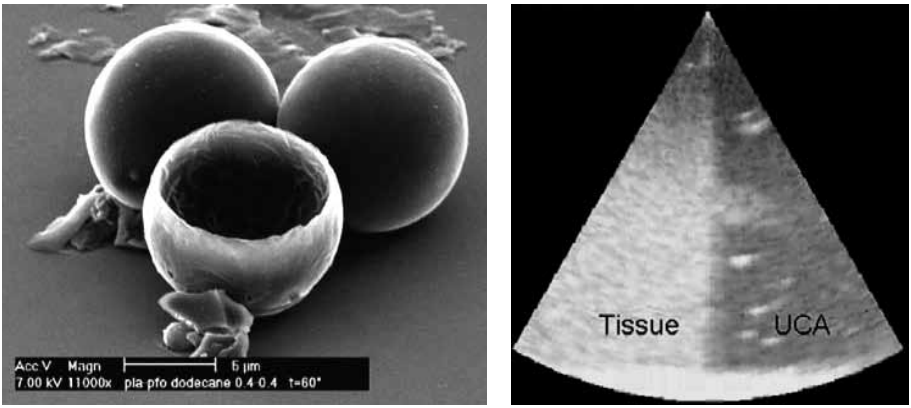

Figure 8. Hollow ultrasound contrast agent (taken from the work of Böhmer et al (2007), and an image from a movie that shows ultrasound contrast agent flaring up on the right side, the left side is a phantom tissue placed there to show the difference in behaviour. The movie was made together with Erasmus Medical Centre; courtesy of Klazina Kooiman and colleagues.

co-solvent that was used was found to be of great influence on the size and strength of the micro-bubbles, and allows for variation in bubble properties.

In ultra sound contrast agent production various time scales need to be matched, the ones of formation and of solidification that should not set in too soon. This implies that the emulsion stability should be tuned, and for that we have also developed tools as described next, although not specifically for ultra sound contrast agents.

Emulsion stability

Making emulsion droplets is one aspect of creating a product, but keeping these droplets stable both during production and storage is a completely different story. For emulsion stability testing we have already developed some microfluidic devices, albeit that they have been tested for a completely different application, namely oil/water separation in crude oil processing within the post doc project of Thomas Krebs. The chip consists of two so-called T-junctions that are not visible in the image but that generate droplets that enter the coalescence chamber from the top and bottom entrance on the left. The droplets flow to the exit on the right, and while doing so encounter other droplets. The process of coalescence when observed with a fast camera is intriguing, since the droplets first catch up with each other, move in tandem for a certain period of time after which they either move away from each other, or the film between the droplets ruptures and coalescence occurs. The movies that are made show these close encounters and allow for very detailed observation of the coalescence process. Here, two droplets are in very close proximity, a small hole is formed in the film, and both droplets rapidly become one larger droplet.

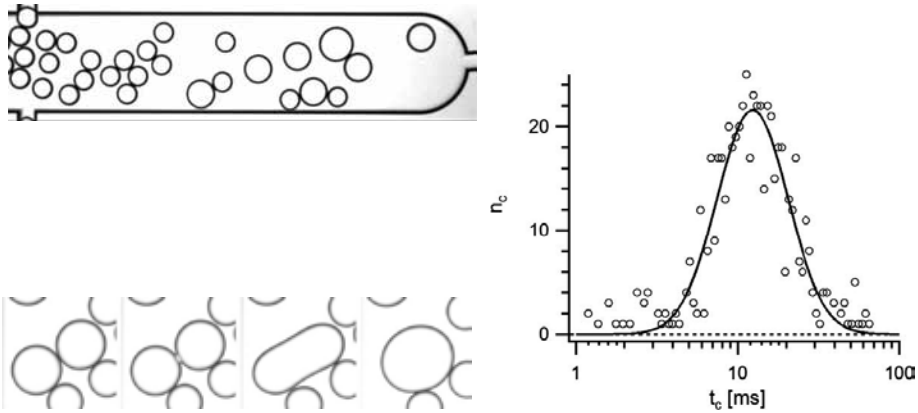

Figure 9. Microfluidic chip with a coalescence chamber for emulsion stability testing (top left image). Bottom left images show four consecutive images showing the coalescence process in detail. Right image, an example of a distribution of coalescence times as measured in the coalescence chamber (Krebs et al, 2012).

Currently, we have tested basic emulsifier systems for systems related to crude oil recovery, and have found that we are able to do systematic investigations, using image analysis of many different coalescence events that we register in the movies. This gives these measurements immediately also the necessary statistical relevance, as illustrated in the graph, and this is completely outside reach when using more classic investigations on droplet coalescence. Also the process conditions that can be tested in this way are very diverse, including shelf-life tests that can even be done under enhanced gravity in a microchip placed on a centrifuge as depicted in this image.

In the images you can see emulsion droplets placed in a small chamber, and at the top a small layer of oil is visible. Upon centrifugation, the droplets are compressed and water is expelled at the bottom. This process continues at longer centrifugation times, with the droplets obtaining a hexagonal shape. In spite of the large deformation, these droplets do not coalesce and remain stable. After shutting the centrifuge down they regain their spherical shape, which is behaviour that was expected for simple surfactant systems.

For food, the challenge will be to investigate food components such as proteins and polysaccharides that not only adhere to interfaces, but flocculate, form networks and all kinds of structures that eventually determine the structure of food. I expect that these aspects can be observed in microfluidic devices, at relevant time scales during formation and storage, and also that components can be systematically evaluated and

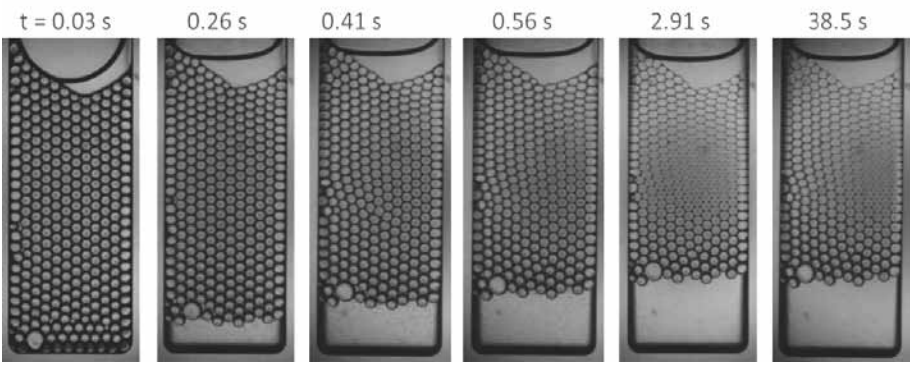

Figure 10. Emulsion compression experiment carried out with a microchip place on a centrifuge (Krebs et al, 2013).

compared, and this gives food microtechnology a special position amongst other analytical techniques.

What is needed to move food microtechnology forward fast?

As mentioned in the title of the lecture, I want to go fast forward for food's future, and that refers amongst others to the movies that we make with high speed cameras, that are actually designed to shoot crash tests. In that respect using these cameras to observe collisions of emulsion droplets is only a matter of different scale. But there is more; the movies that we make within the various topics that we study allow for observation of phenomena at time scales that are essential for the formation of food structures, and the separation of food components. I think that the specific knowledge that we gain from these investigations is unique, and will allow for radically different design of foods and of the processes that are carried out to obtain them, and in that respect has the potential to move food science and food process engineering into fast forward mode.

I have shown you early on in the lecture very energy efficient emulsification and fractionation as examples of how processes can be designed very differently based on the new insights that were generated at micrometre scale. Whether these systems are the best possible designs is still under discussion, and depends also on the scale at which they should be applied. For example the EDGE emulsification system can be used to make very monodisperse droplets, but the question is whether the productivity of the system is high enough to allow for application in a bulk product, or should be used for specialty products. Irrespective of this, the insights that were gained are very valuable, and allow us to understand similar systems faster. We

currently compare various emulsification techniques, all based on microstructured devices such as membranes, and sieves with uniform pores, but also try to emulate what we have learned from the microfluidic systems into derived larger scale operations. A nice example is the use of beds of glass beads as an alternative membrane structure that can be formed and disintegrated at will therewith preventing the fouling issues that are always related to membrane emulsification as demonstrated in the projects of Eduard van der Zwan and Akmal Nazir.

When I started my lecture, I mentioned the use of stainless steel, and that is still the preferred material in industry, therefore we also made a start working with metal surfaces. Since it is not so trivial to work with stainless steel in microfluidics we started with another metal, copper and the chip is shown here. What is not visible is that the surface when looking at micrometer scale is not as smooth as in the chips that I showed before, actually the surface looks a bit like an alpine landscape when viewed on that scale. Irrespective of this, these microfluidic devices are able to make uniform droplets, and that indicates that metal devices could be a way to continue. An alternative route is to go to polymer-based systems as for example described by Vogelaar for microsieves, and duplicate small structures in this way. Which of the options will be the winner is still to be seen, but there is clearly hope that also microfluidic systems can be scaled up by parallelisation.

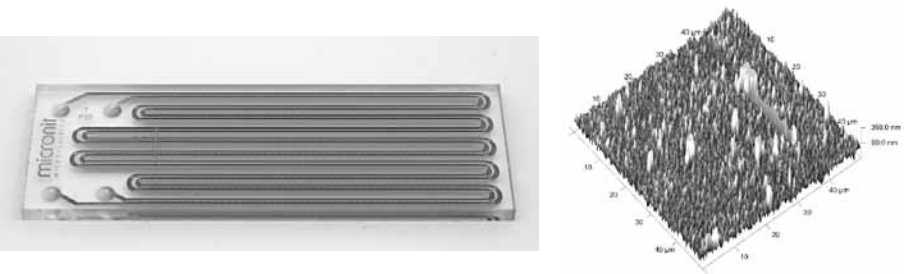

Figure 11. Copper containing microchip for emulsification (left image), and a roughness plot obtained by atomic force microscopy of the same surface (right image) (Maan et al, 2013).

Besides in processes, I think that food microtechnology can help in faster evaluation of component properties. The tools that currently are available, and that we will keep designing, are ultimately suited to compare functionality at the scales that are determining the stability of the food during formation, further processing and also later on while remaining on the shelf. As such, this technology holds a unique position that will allow investigations that previously were outside reach.

Regarding the products that can be made, food microtechnology is currently limited to foods that are able to flow, which implies that they are completely liquid at the stage of formation, but may contain small solid particles, or air bubbles, and may even undergo a phase transition as long as solidification does not set in too fast. You have already seen many examples of what is possible, and obviously many food products are very compatible with the approach that was chosen. Besides, you have also seen the examples that are more related to health, such as the capsules, and the ultrasound contrast agents, and in all these applications we will stay active.

Away from applications, and large scale production, food microtechnology can be used to investigate fundamental aspects such as for example dynamic interfacial tension during droplet formation, and most probably it can also be used to probe surface rheology. For simple components, dynamic interfacial tension was already reported in the project carried out by Maartje Steegmans, but for more complex food components such as proteins and polysaccharides this will be a genuine challenge, given the myriad of interactions that may take place.

In order to make most out of the options that are available, there are two elements that I would like to mention, that are prerequisites for making fast progress. The first one is surface modification, and in this case I mean the surface of the microfluidic device. Surface modification research has been part of a long standing collaboration with the organic chemistry group as reflected in amongst others the projects of Ahmad Arafat and Michel Rosso, and is needed in case certain components preferentially interact with the chip surface. For example if components change the wettability of a chip, emulsification is no longer possible, and this needs to be prevented to be successful, and we have shown that so-called inert surfaces need to be protected appropriately.

A second aspect that needs to be developed in tandem with experimental work is computer simulations. In the projects of Sandra van der Graaf and Koen van Dijke this was an integral part of the work, and that helped deepen understanding of underlying mechanisms, eventually leading to scaling relations that can be used to design processes. The combination of experimental and computation work has proven to be very valuable, and will remain an essential part of the work carried out within the food microtechnology group, both for the separation and the emulsification work.

If we are able to bring all these aspects together, and I don't doubt that this is what we will be able to do, I am sure that we can put developments in fast forward mode, and truly work on the design of the foods of the future, and make professor Leniger's

words on science not contributing to the development of the food industry obsolete. In order to do so, I incorporate the findings from my group in the regular courses that we teach to our students, and hope that they take this message to their prospective employers. With that I would like to conclude the scientific part of my lecture and move to the personal part.

Acknowledgement/Dankwoord

Today I stand in front of you gratefully accepting the personal chair in food microtechnology. I feel very fortunate to be in this position, and many people have contributed to this milestone. The first one to notice my inquisitive scientific mind was Jos Keurentjes with whom I did my MSc thesis. He had to laugh very loudly, and rightfully so, when I announced very early on in the project that science was not for me and that I preferred a career in industry after completing my thesis! That was fortunately not to become a reality, because Klaas van 't Riet, and Albert van der Padt, today also present here, asked me even before I finished my MSc thesis whether I would like to work at the food and bioprocess engineering group. At that time I had already changed my mind regarding doing research, but they only had financial means for 2 years. I insisted that I wanted a PhD project of 4 years, and they made this happen without seemingly thinking twice. Klaas and Albert, I greatly appreciate that you created this opportunity for me: it was a truly joyous start of my scientific career. For that, Martien Cohen Stuart was co-responsible. He joined our team a bit later, but became an essential part of it; thank you for what you call applied aspects and I call fundamentals.

After a post-doc position at University College in London, where I learned how to work within a completely different research setting, it was time to return to the Netherlands. For this I am very grateful and indebted to Anja Janssen, who hired me for a research project on antibiotic synthesis. Together with three other people I worked on the project, in various team compositions. At the closing stages of that project, Albert van der Padt decided to pursue a career in industry, and I need to thank Remko Boom for having confidence in me and offering me the job of my former supervisor that I was honoured to take. During the entire route leading from assistant professor to being here today, I have been supported by Remko Boom and the entire food process engineering team, successfully working on various aspects of what now has become the field of food microtechnology, and I would like to thank you all for your support.

During my entire career, I have been in the fortunate circumstance to work with many talented people, be it my direct colleagues in the food process engineering staff, or post docs, PhD, MSc & BSc thesis students, or the students that take our courses. It is a great pleasure to work with you all on a daily basis. Dear students: what makes me go to work with a smile on my face is knowing how great you already are and that I am in a position to make you shine even brighter, which I consider a privilege that is as special as it was when I started off as an assistant professor. Thank you for inspiring me!

Within my research activities I have collaborated with many industrial and academic partners. I greatly appreciate all our joint discussions that have helped to increase the impact of our research. I especially like to thank the NanoNextNl initiative and the Institute for Sustainable Process Technology, and all connected partners since they are an essential part of the research that we do. Besides I would also like to specifically mention the longstanding collaborations with the physical chemistry and colloid sciences group of first Martien Cohen Stuart, and now Jasper van der Gucht, the organic chemistry group headed by Han Zuilhof, and all the food technology groups. It is a great pleasure to work with all of you, and I hope to strengthen the existing bonds even further.

The fact that I am here today, is a result of the tenure track system that is now in place within Wageningen University, and that gives young aspiring scientists a genuine career perspective. I am grateful that our university decided to establish this system, which I entered in July 2010. I would like to mention the support of the first tenure track class of associate professors that I became part of, and that put things in a much clearer perspective. I appreciate the open atmosphere in that group. It really helps to talk to people that are in the same situation, and to the coaches, so thank you all very much!

The title of my lecture today starts with fast forward, and that also reflects the tenure track that put my career in fast forward mode. Since there are so many aspiring young people in the audience, I would like to call on them to embrace the opportunities that previously did not exist. The tenure track is challenging, no doubt; but it is a great chance to move your career forward, and I especially would like to call upon the young women in this audience to just go for it! It still amazes me that I am the first appointed female professor in food technology. While I truly feel very honoured because of this, I do not know why it took so long, since as long as I know there has been a majority of very talented female food technology students …. Don't get me wrong, my colleague male food technology professors are very bright and a pleasure to work with, but with so many talented women around, it should only be a short matter of time before many more women follow suit; at least that is what I sincerely hope for.

For the last part of this acknowledgement, I would like to switch to the Dutch language. Het ging zojuist over getalenteerde mensen, en dan is het maar een kleine stap naar het softbalteam dat ik mag coachen. In de winter hebben we gezegd dat we het slimste team van Nederland wilden zijn, en dat is zeker gelukt want we hebben onderhand een heel compleet spel waar geen ander team in onze klasse aan kan

tippen. Ik vind het fantastisch om met dit team te mogen werken; heel fijn dat jullie er vandaag ook bij willen zijn!

In de laatste maar zeker niet minste plaats wil ik mijn familie bedanken. Het is jammer dat pa er niet meer bij is, want hij had het vast een 'optrekkende' dag gevonden. Wat dat betekent dat kan eigenlijk alleen iemand met de naam Schroën, of iemand die daar heel stevig mee verbonden is ten volle begrijpen, en ik ga het ook niet proberen uit te leggen, maar het vat wel alles wat ik wil zeggen adequaat samen. Ik hoop dan ook dat vandaag voor jullie een optrekkende dag is, die overigens nog lang niet afgelopen is, want er staat onder andere nog heel veel lekker eten op ons te wachten.

Geachte aanwezigen, het is niet mogelijk om iedereen persoonlijk te bedanken vandaar dat ik kort en krachtig ga afsluiten. Dank voor jullie interesse en voor jullie aandacht.

Ik heb gezegd!

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Prof. dr *ir*. Karin Schroën

'Foods and food ingredients are produced at very large scale on a daily basis; however, insight in the underlying mechanisms that take place at micrometre scale is lacking. This is because of the small scale and the high speed at which things occur. Food microtechnology combines investigation in small channels for example in microfluidic devices with high speed imaging and modelling, and uses this to push the food process technology of the future in fast forward mode.'

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